Transverse Impedance Distribution Measurements Using the Response Matrix Fit at APS

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Acknowledgements

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Procedure description

- The beam sees the transverse impedance as defocusing quadrupole whose strength depends on the beam current
- At APS we use the response matrix fit method for measurement of beta functions along the ring
- We use this method to measure beta functions for different beam currents, then we calculate local phase advance changes with beam current, then we determine the transverse impedance

Response matrix fit (LOCO)

- Orbit response matrix is the change in the orbit at the BPMs as a function of the changes in the steering magnets
- The response matrix is defined by the linear lattice; therefore, it can be used to calibrate the linear optics
- Accelerators have a large number of steering magnets and precise BPMs, so the response matrix measurement generates a very large array of precise data
- The idea of the analysis is to adjust all variables upon which the response matrix depends in a computer model until the model response matrix best fits the measured response matrix

Response matrix analysis

The measured response matrix depends on the following parameters:

- Quadrupole gradients
- Steering magnet calibrations
- BPM gains
- Energy shift associated with steering magnet change
- BPM nonlinearity
- Steering magnet and BPM longitudinal positions

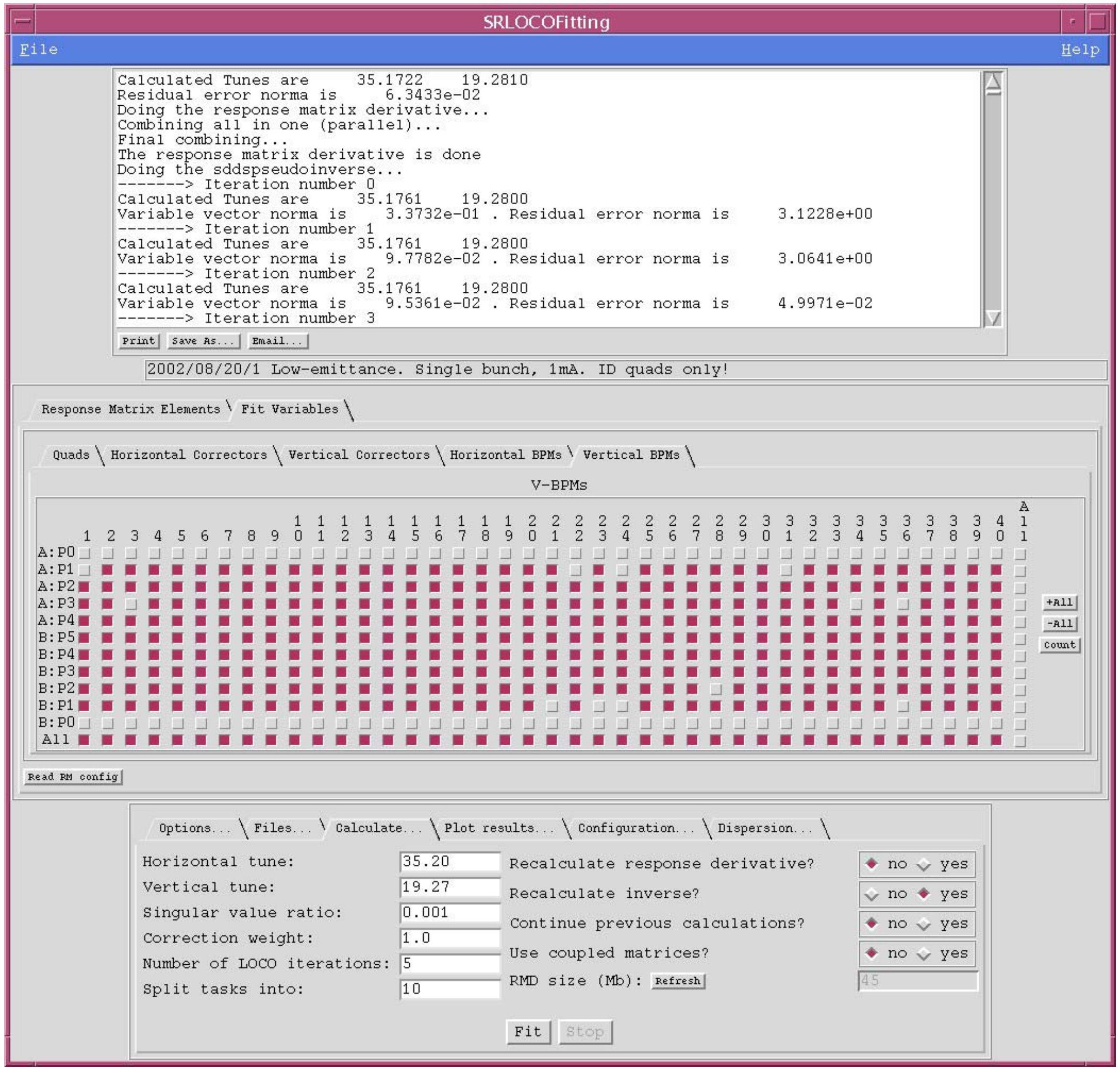
Main parameters

Totally, we vary about 1,400 variables to fit 32,000 elements of the response matrix

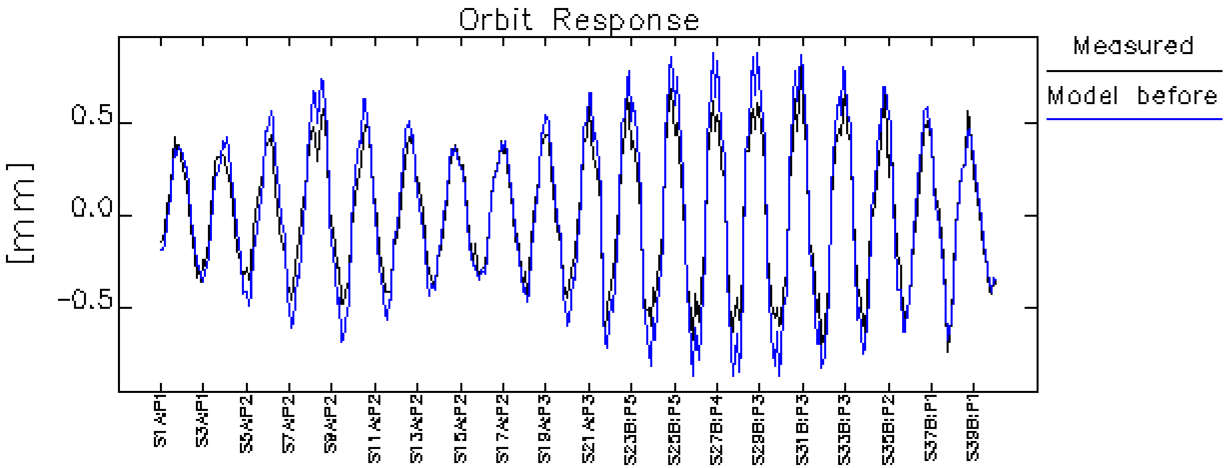
Implementation

- The problem is divided into two pieces: measurements and data fitting
- The programs are implemented on Unix/Solaris
- Graphical User Interface is written in tcl/tk
- sdds code `elegant` is used for all accelerator-related calculations
- All data manipulations during the measurements and fitting are done using sdds tools

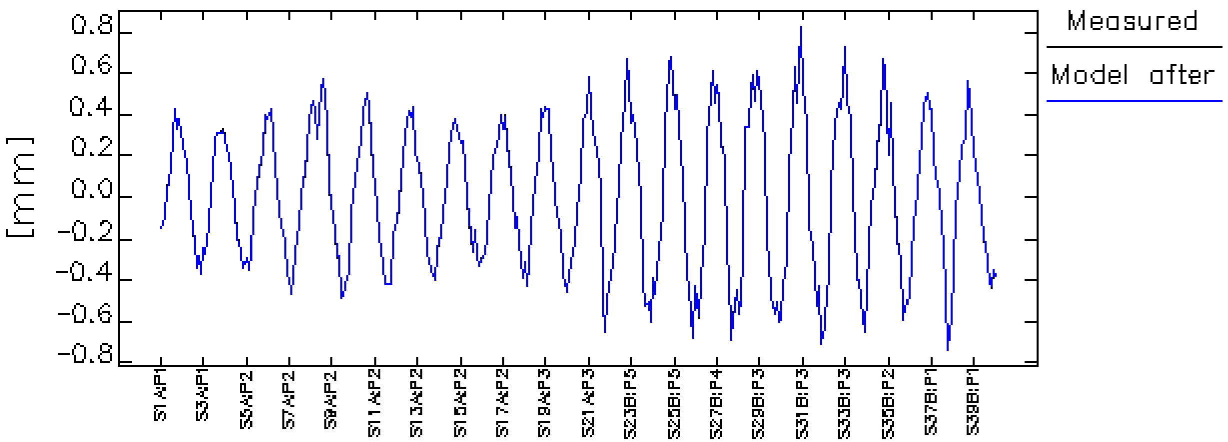
GUI example


SRLOCOFitting
File
Help
Calculated Tunes are 35.1722 19.2810
Residual error norma is 6.3433e-02
Doing the response matrix derivative...
Combining all in one (parallel)...
Final combining...
The response matrix derivative is done
Doing the sddspseudoinverse...
-------> Iteration number 0
Calculated Tunes are 35.1761 19.2800
Variable vector norma is 3.3732e-01 . Residual error norma is 3.1228e+00
-------> Iteration number 1
Calculated Tunes are 35.1761 19.2800
Variable vector norma is 9.7782e-02 . Residual error norma is 3.0641e+00
-------> Iteration number 2
Calculated Tunes are 35.1761 19.2800
Variable vector norma is 9.5361e-02 . Residual error norma is 4.9971e-02
-------> Iteration number 3
Print
Save As...
Email...
2002/08/20/1 Low-emittance. Single bunch, 1mA. ID quads only!
Response Matrix Elements
Fit Variables
Quads
Horizontal Correctors
Vertical Correctors
Horizontal BPMs
Vertical BPMs
V-BPMs
A:P0
A:P1
A:P2
A:P3
A:P4
B:P5
B:P4
B:P3
B:P2
B:P1
B:P0
All
+All
-All
Count
Read RM config
Options...
Files...
Calculate...
Plot results...
Configuration...
Dispersion...
Horizontal tune: 35.20
Vertical tune: 19.27
Singular value ratio: 0.001
Correction weight: 1.0
Number of LOCO iterations: 5
Split tasks into: 10
Recalculate response derivative? no yes
Recalculate inverse? no yes
Continue previous calculations? no yes
Use coupled matrices? no yes
RMD size (Mb): Refresh
45
Fit
Stop

Measurements and fitting



Typical rms error before the fit: 80 μm

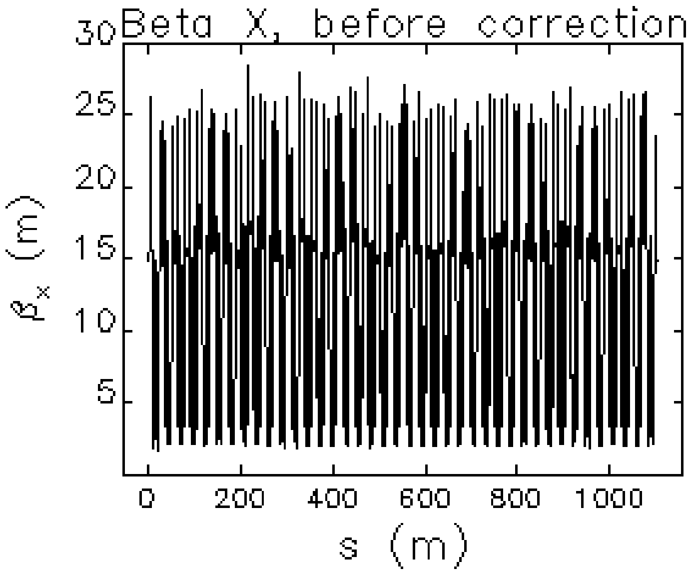


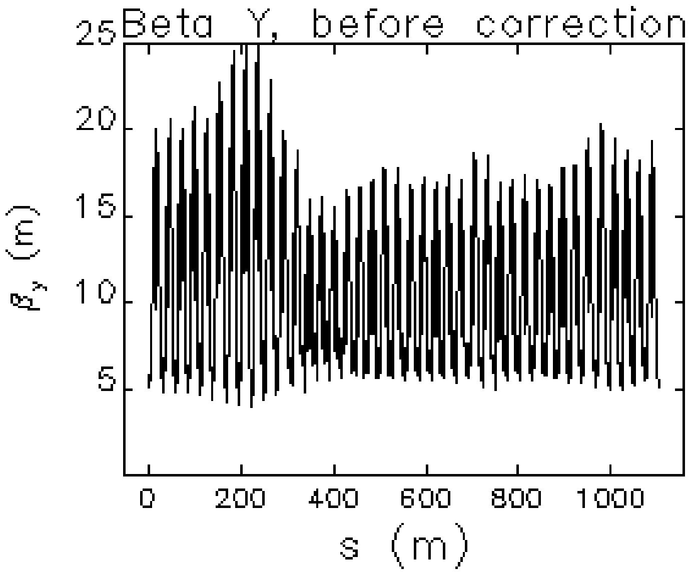
Typical rms error after the fit: < 2 μm

After the fit is done…

The result of the fit is the “parameter” file for `elegant` containing quadrupole errors, BPM gains, and corrector calibrations. This file represents the real model of the machine and can be used for different kinds of calculations in `elegant`.

Beta functions calculation (08/08/2001):

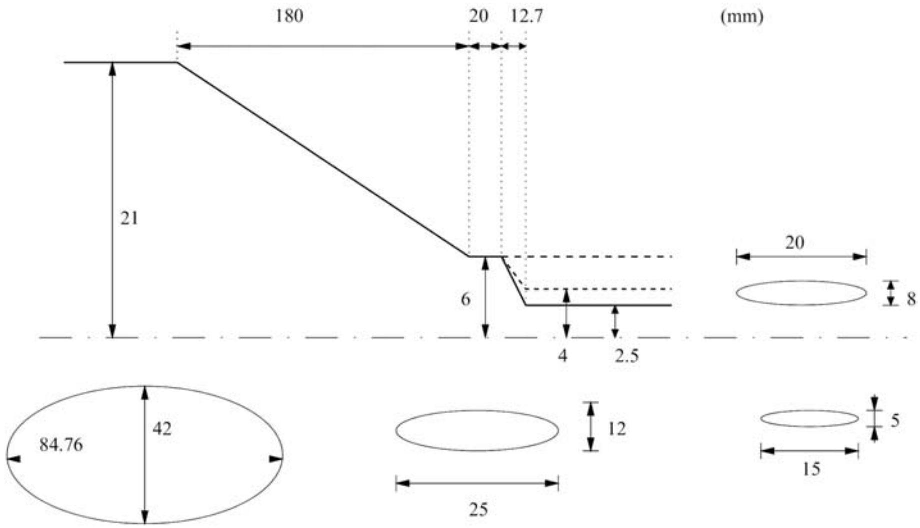




Exploitation of the model

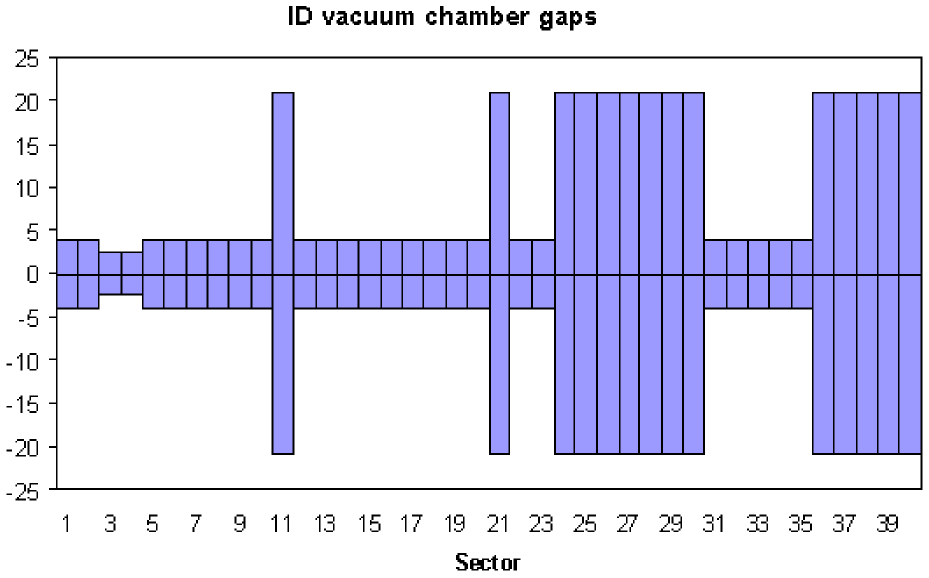
- Improving the performance of the existing machine
  - Beta function correction - to improve lifetime, injection efficiency, chromaticity correction
  - BPM gain calibration
- Creation of new lattices
  - Increasing brightness of x-rays by decreasing the beam emittance (from 7.7 nm·rad to 2.4 nm·rad)
  - Exotic lattices:
    - Long straight section for one particular user
    - Low beta straight section to decrease the source size
    - Converging beta function to increase x-ray flux density
- Learning new things about the machine
  - Local impedance distribution

Vertical impedance sources



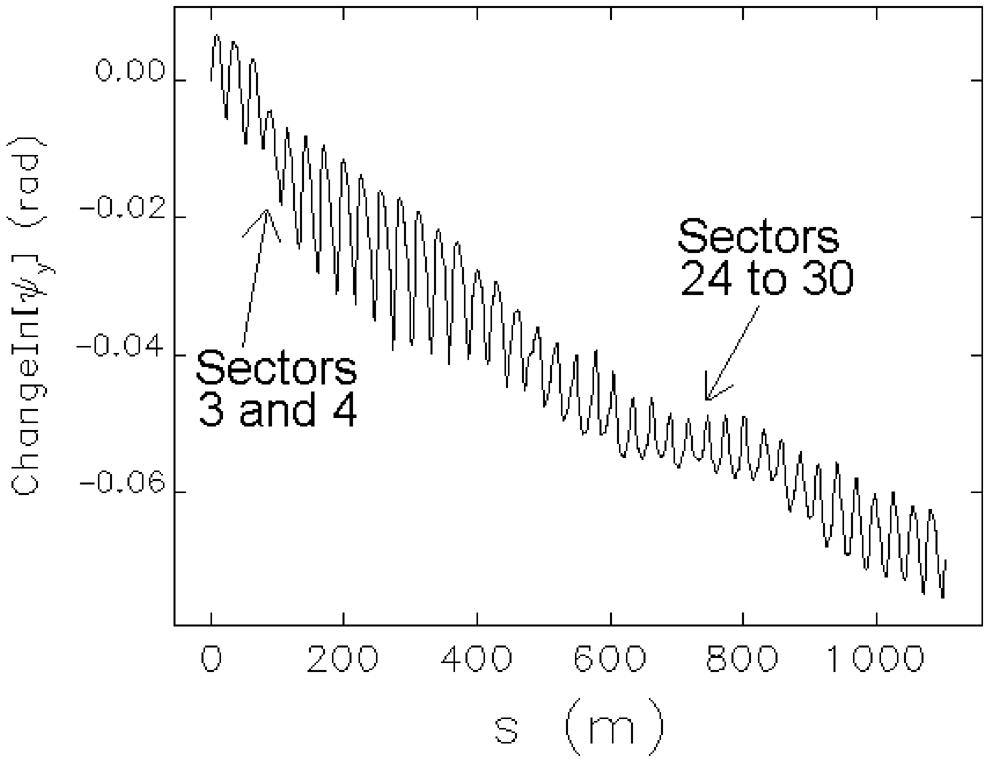
Geometry of the transition between large- and small-gap vacuum chambers

Locations of the small-gap ID vacuum chambers; each ID chamber is 5-m long aluminum extrusion



Measurements

In order to obtain the change in focusing with the beam intensity, we measure the response matrices for different beam currents, analyze them to get beta functions, and then compare the local phase advances.

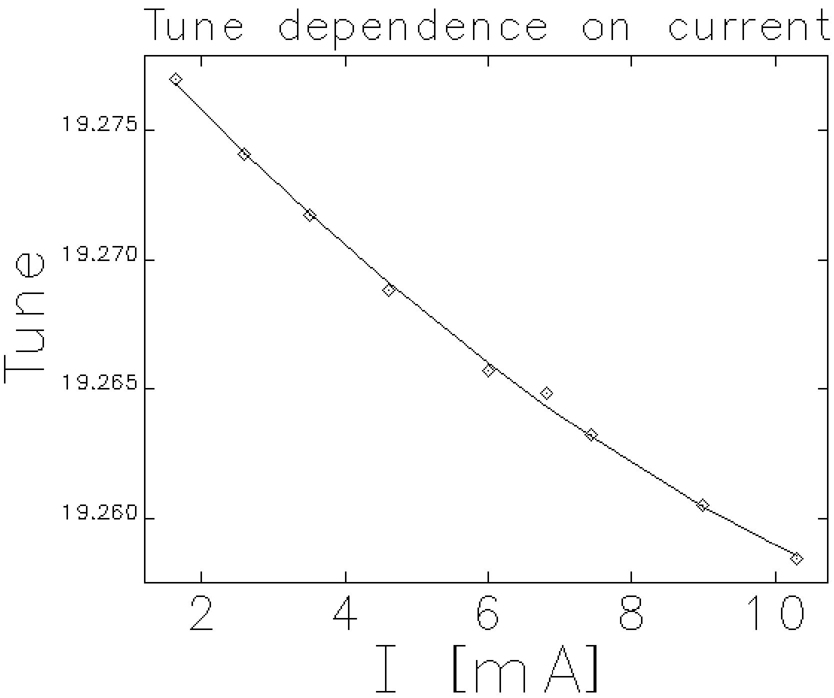


Betatron phase advance difference between 10 mA and 1 mA (in a single bunch)

Tune slope with current

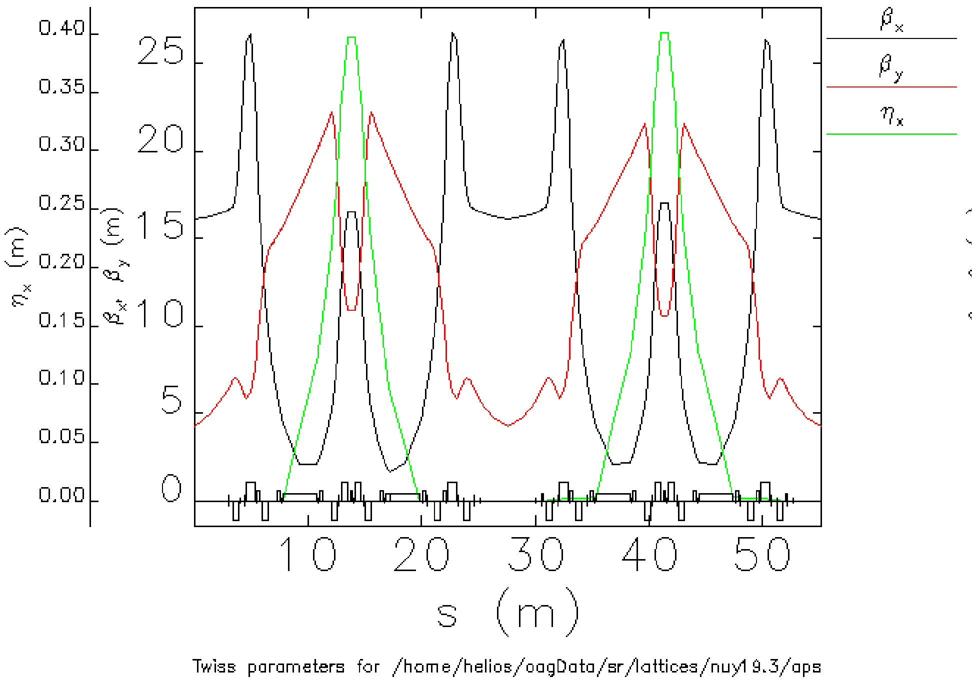
The measurement also yields the tune slope with current, which can be used to calculate the total transverse impedance. The plot shows vertical betatron tune dependence on the beam current defined by the following formula:

$$\frac{d\nu}{dI} = \frac{R}{2\pi\sigma_s E}\sum\langle\beta\rangle_i Z_{eff}^{(i)}$$

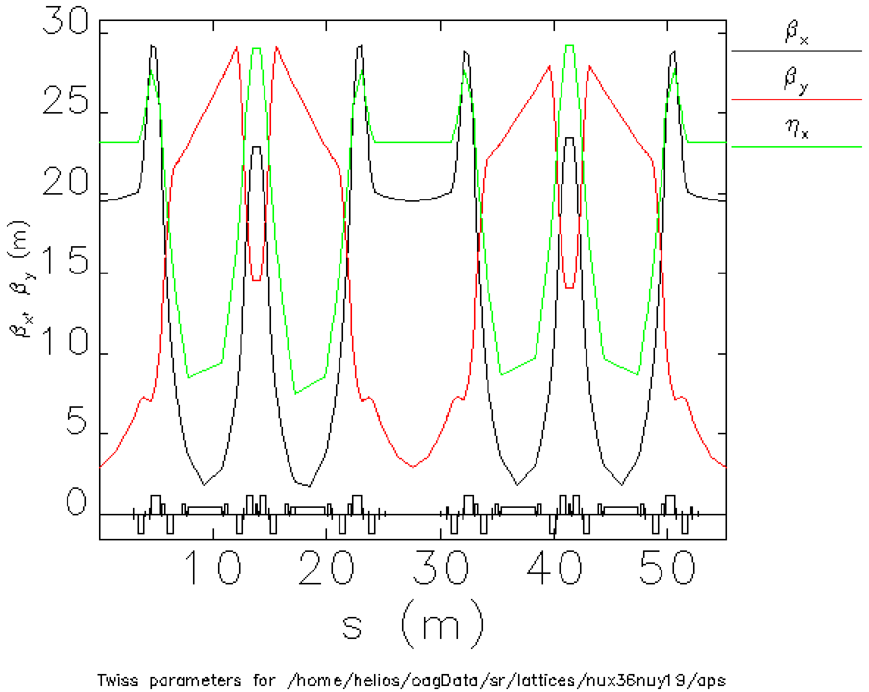


Beta functions

High emittance



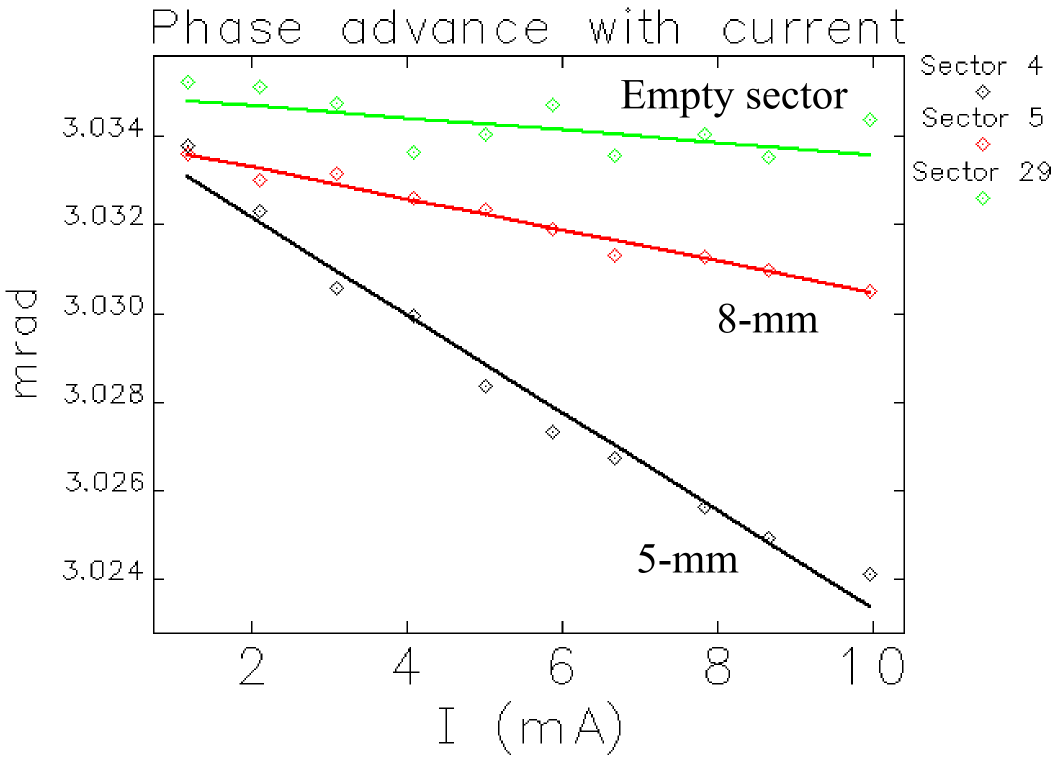
Low emittance



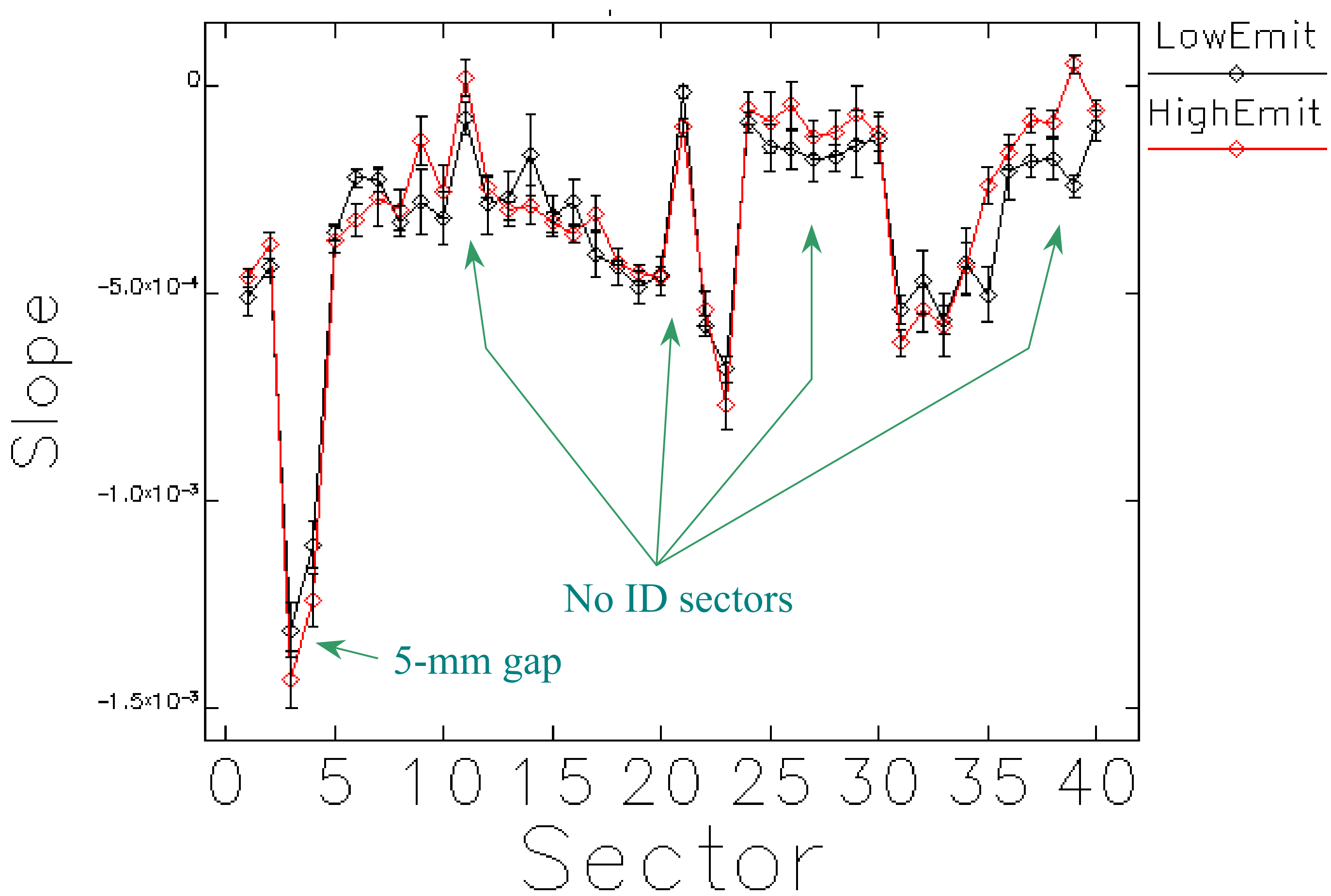
Measurements

To get the local distribution of the impedance, we analyze the phase-advance changes sector by sector.

Typical phase-advance slopes for sectors with 5-mm, 8-mm, and 42-mm-gap vacuum chambers are shown below.



Vertical betatron phase slope distribution



Vertical impedance calculation

For a particular component, the effective impedance can be found from measured slopes of the phase advance:

$$Z^i_{eff} = \frac{E/e\,\sigma_s}{R\beta_i}\frac{d\mu}{dI}$$

	Units	High emittance	Low emittance
$d\mu/dI_{no\ ID}$	A^{-1}	-0.09	-0.14
$d\mu/dI_{8mm}$	A^{-1}	-0.39	-0.40
$d\mu/dI_{5mm}$	A^{-1}	-1.33	-1.21
Z^{eff}_{noID}	kΩ/m	3.5	4.1
Z^{eff}_{8mm}	kΩ/m	31	34
Z^{eff}_{5mm}	kΩ/m	126	138
Z^{eff}_{total}	MΩ/m	1.1	1.2

Conclusion

- Vertical effective impedance distribution has been determined using the response matrix fit
- It was found that the small-gap ID vacuum chambers contribute the most to the storage ring vertical impedance
- The actual values of the vertical impedance of the chambers with different gaps were determined
- The results compare well with the impedance model (presented yesterday) and with the earlier measurements using local orbit bumps (PAC2001 by L. Emery)

Future plans

- Confirm the impedance source in the ID straight section: the transitions or the resistive wall
- Extend the impedance measurements to the horizontal plane
- Extend the response matrix analysis to the coupled motion

- ??? Help to apply the technique to Tevatron ???